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"MIX AND MATCH": PRODUCT COMPATIBILITY WITHOUT NETWORK EXTERNALITIES

Carmen Matutes, INSEAD, Fontainebleau

Pierre Regibeau, Sloan School of Management

WP1929-87 Revision of April 1987

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INTRODUCTION

Many multiproduct industries sell 'systems', i.e lines of products where each good cannot, or usually is not, used separately but might still be bought separately. Examples of such industries are the computer industry, where a 'system' involves both hardware and software, and the amateur photography industry, where the typical product line includes cameras, lenses, negatives and film processing services.

In some of these industries, every component of a system produced by a firm can be used with every component manufactured by another firm. This is the case for the home-stereo industry where, for example, a Sanyo tape deck can be combined with a Pioneer receiver and Kenwood speakers. Such industries are referred to as (fully) compatible.

In other instances, the systems produced by different firms are not compatible at all, as exemplified by the video industry where VCRs and Beta recorders coexist.

To the extent that compatibility, or the absence thereof, results from a conscious decision by manufacturers, the firms' incentives to produce compatible products and the social optimality of such incentives must be examined.

In the -by now standard- framework first explored by Katz-Shapiro(1985) and Farrell-Saloner(1985), a system of

compatible components is treated as a single good characterized by positive consumption externalities. Such 'network externalities' arise because consumers'enjoyment of a system increases with the number of other consumers using compatible products. The larger the 'network' of compatible goods is, the better are the possibilities of exchange, the quality of after-sale services and the information available.

With network externalities, the firms'incentives to produce compatible systems and the social optimality of these private incentives have been shown to depend on the firms' relative size and on how compatibility can be enforced. If compatibility can only be achieved with the agreement of all firms (adoption of a common standard), any privately profitable industry-wide standard is socially desirable, but some socially desirable standardization will be rejected. If, on the other hand, standardization can be enforced unilaterally (by building an adapter) and firms differ greatly in sizes, private incentives to standardize might be too high (see Katz-Shapiro 1985).

These welfare results are criticized by Farrell and Saloner (1985c) who argue that standardization has an extra social cost since it reduces product variety. They show that if the trade-off between network externalities and product variety is explicitly considered, the firms' incentives to produce compatible products can more easily be socially excessive.

Although Katz-Shapiro and Farrell-Saloner recognize that issues of standardization mostly arise in industries producing 'systems', they model the firms as selling a single good. This implicitly assumes either that every firm sells every component of a system treated as a homogenous good or that the firms each sell one similar (e.g. software) component to consumers who have already bought the rest of the 'system' (e.g. the personal computer).

The purpose of this paper is to show that additional insights about these issues can be gained by explicitly considering a system as a set of components instead of treating it as a single good.

We consider industries where each firm has a full line of products, in the sense that it sells every component of a complete system. Two main arguments are developped.

First, contrary to Farrell and Saloner's argument, product compatibility might indeed increase the range of consumers' choices. If compatibility prevails, consumers can assemble their own systems by buying components from different firms. If, on the other hand, the components manufactured by different firms are not compatible, the buyers must purchase the full system from a single supplier. The number of different systems available to consumers is thus greater when the firms produce compatible components. It follows that compatibility enables some

consumers to obtain a system whose features are closer to their ideal.

Secondly, we show that, even in the absence of network externalities, there are incentives for the firms to produce compatible systems. Indeed, in a game where firms decide whether or not to make their system compatible before competing on prices and, compatibility is shown to be the unique outcome of symmetric perfect Nash equilibria whenever standardization can be enforced unilaterally. This is the result of two effects. First, as was just mentioned, compatibility enables consumers to get a more satisfactory system. This shifts the consumers' demand curves upwards, making the market more profitable. Second, compatibility weakens the firms' incentives to cut prices. When firms sell incompatible components, a decrease in one firm's price increases its sales at the expense of its rivals' sales. With compatibility however, cutting the price of one good will increase the sales of all systems using this component, including systems which combine it with components produced by other firms. In other words, some of the benefits of the price cut will not be appropriated by the price cutting firm so that firms will behave less aggressively than in the case of incompatibity.

Finally, it is shown that the move from an incompatible to a compatible industry unambiguously decreases the welfare of some consumers, while it makes some other consumers better off. Consumer surplus and social surplus

(gross of standardization costs) are also shown to be generally higher when full compatibility prevails. If standardization costs are introduced however, compatibility can arise as the equilibrium outcome of the game, even though it is socially inferior to incompatibility.

The basic model is presented in section 1 and the symmetric equilibrium prices under compatibility and incompatibility are determined in section 2. Section 3 ranks the firms' profits in the two equilibria, while section 4 examines the welfare implications of compatibility. Section 5 extends the analysis to cases where the market is not completely served and provides more precise welfare results, while section 6 proposes an alternative intuition for the results obtained. Section 7 examines the incentives for firms to produce partially compatible systems, and section 8 discusses the firms' incentives to offer tie-in discounts. Section 9 briefly summarizes the results, discusses their applicability and suggests a few areas for future research.

I. THE MODEL

1. Systems and Components

Two firms, A and B, each manufacture a 'system' made of two components. Define X_{ij} as the i^{th} component produced by the j^{th} firm ($i = 1,2$ and $j = A,B$). If the components sold by the two firms are not compatible, only two systems are available for the consumers to purchase : firm A's system, X_{AA}, which combines X_{1A} and X_{2A}, and firm B' s sytem, X_{BB}, combining X_{1B} and X_{2B}.

If the components produced by the two firms are all compatible, consumers can choose among four systems :

- X_{AA}, which includes X_{1A} and X_{2A}
- X_{AB}, " " X_{1A} and X_{2B}
- X_{BA}, " " X_{1B} and X_{2A}
- X_{BB}, " " X_{1B} and X_{2B}.

2. Firms

The following two-stage game is solved for its symmetric perfect Nash equilibrium. In the first stage, each firm simultaneously decides whether or not to make its components compatible with its rival's. In the second

stage, firms compete on prices, taking the other firm's prices as given, i.e. firms behave as Bertrand competitors.

Both firms produce the two components of a system and choose their two-stage strategies in order to maximize their own profits. Each component is produced at a constant marginal cost and there are no economies of scope. Without loss of generality, the marginal costs are all set equal to zero.

There are two different games, according to whether or not a consensus is required for the two firms to achieve compatibility. In the first case, compatibility can be achieved unilaterally, i.e. it can be enforced by any one firm. This occurs whenever a firm can make its components compatible with its rival's by builiding a cheap adaptor(i.e. by making them 'plug-compatible'), and will thus be referred to as 'the adaptor case'. In the second case, compatibility can only arise if both firms agree to it. Such a situation can arise if each firm has a choice between two standards : a 'common knowledge' technology, accessible to both firms and a technology which is inaccessible[2] to its rival. In this setting, compatibility can only prevail if both firms choose the common-knowledge technology.

3.Consumers

The consumers are uniformly distributed on the unit square (see figure # 1), where firm A is located at the

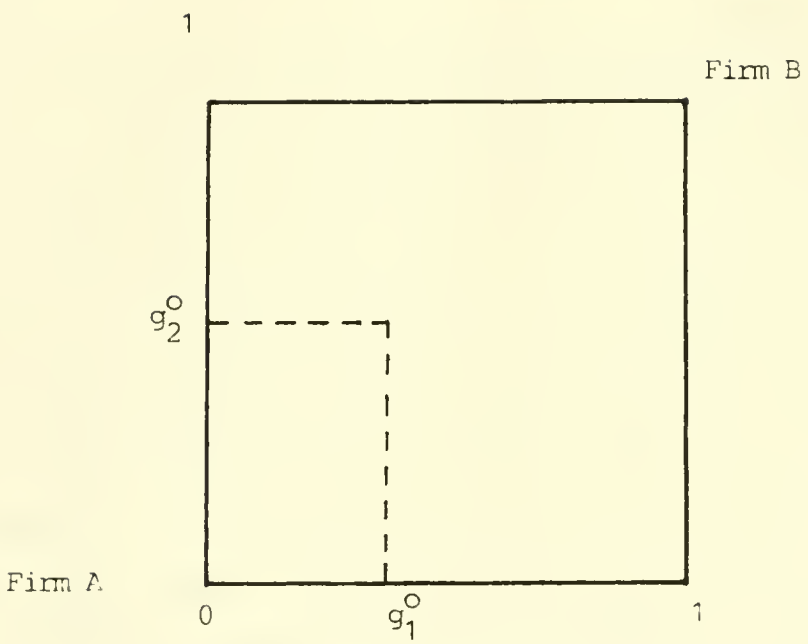


FIGURE 1

origin, while firm B is located at the point of coordinates $(1,1)$[3].

A consumer located at a point of coordinates (g_1^o, g_2^o) has a preferred first component which is g_1^o away from firm A's first component and a preferred second component which is g_2^o away from A's second component. Similarly, the 'distances' between the consumer's preferred point and B's components are $1-g_1^o$ and $1-g_2^o$.

Each consumer has preferences represented by a utility function which is separable in X, the quantity of the system purchased, and a numeraire good Y :

$$U = V(X) + Y$$

with :

$$V(X) = (\frac{C}{D} - d_1 - d_2)X - \frac{X^2}{2D}$$

where d_i is the 'distance' between the consumer's preferred specification of the i^{th} component and the specification of the i^{th} component included in the system.

Each consumer maximizes U(X,Y) subject to a budget constraint, or, equivalently, maximizes his/her surplus :

$$V(X) - PX$$

where P is the price of the system in terms of the numeraire good. Inverting the first order condition of this maximization problem yields the direct demand function :

$$X = C - D(d_1 + d_2) - DP \quad \text{for all } P \text{ s.t. } X > 0 \qquad (1)$$

This is indeed just a 'spatial' model where the actual price paid by the consumers is equal to the 'mill price' P_j plus 'transportation costs' $d_{1j} + d_{2j}$.

In such a framework, the consumer's choice of X is a two-stage process. In the first stage, the consumer chooses the system that maximizes her/his indirect surplus function, i.e. the system j for which $P_j + d_{1j} + d_{2j}$ is minimum[4]. In the second stage, the consumer purchases $X = C - DP_j$ units of the preferred system.

As a matter of convenience, it will be assumed that a given individual consumes the two components of the system in fixed proportions. Allowing the proportion to change with prices would only make the computations harder. It will also be assumed that every consumer purchases the two components in the same proportion of λ units of good 1 to each unit of good 2. From now on, λ will be set equal to 1; the results for $\lambda \neq 1$ can be found in appendix A.

II. EQUILIBRIUM PRICES

Troughout this section, it will be assumed that the whole market is served, i.e. that

$$C - D[\min_{ij} (P_{ij} + d_{ij})] \geq 0 \quad \text{for all } g_1, g_2 \in [0,1],\ i,j = A,B$$

where P_{ij} is the price of the system X_{ij} and d_{ij} is the 'distance' between X_{ij} and the best preferred system of a consumer located at (g_1, g_2). The cases where some consumers are not served in equilibrium are discussed in section 5.

1. Incompatibility

If all the consumers purchase the two components in the same proportion of one to one, a consumer located at (g_1, g_2) will choose firm A's system (X_{AA}) over firm B's system (X_{BB}) if and only if :

$$P_A + g_1 + g_2 \leq P_B + (1-g_1) + (1-g_2)$$

so that consumers will buy from A or B depending on whether they are located below or above the line :

$$g_2 = \frac{P_B - P_A}{2} + 1 - g_1 \qquad (2)$$

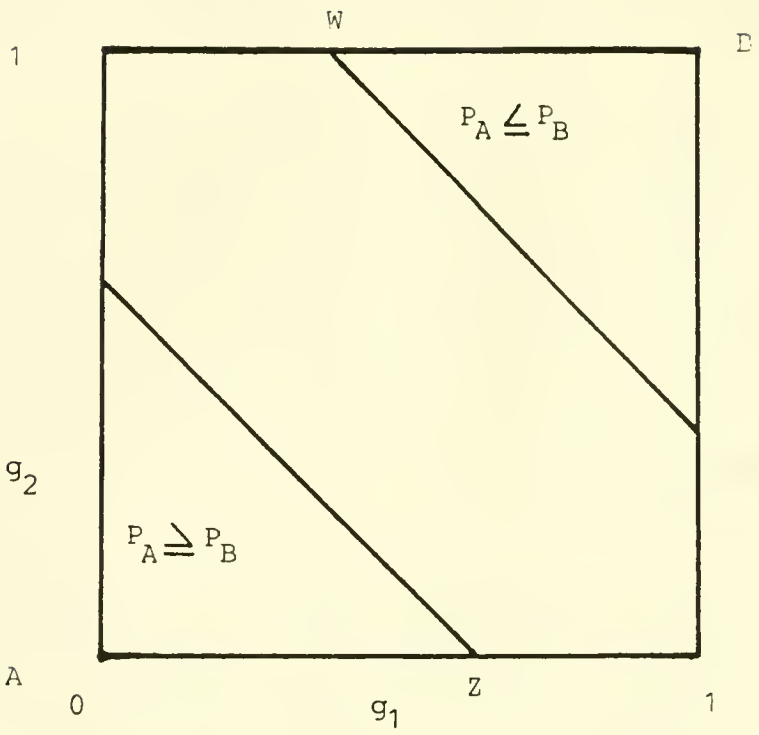


FIGURE 2

Two cases must be considered (see figure # 2).

If $P_A \geq P_B$, firm A's profits can be written as :

$$\pi_A = P_A \int_0^Z \int_0^{Z-g_1} [C - D(P_A + g_1 + g_2)]dg_2\, dg_1 \qquad (3)$$

where $Z = \frac{P_B - P_A}{2} + 1$.

If $P_A \leq P_B$, firm A's profits can be written as :

$$\pi_A = P_A \int_0^W \int_0^1 [C - D(P_A + g_1 + g_2)]dg_2\, dg_1 \; + \; P_A \int_W^1 \int_0^{W+1-g_1} [C - D(P_A + g_1 + g_2)]dg_2\, dg_1 \qquad (4)$$

where $W = \frac{P_B - P_A}{2}$.

Maximizing (3) or (4) with respect to P_A[5] and imposing symmetry (i.e. $P_A = P_B$) in the first order conditions yields :

$$DP_I^2 - (C+D)P_I + (C - \tfrac{2}{3}D) \qquad (5)$$

the roots of which are :

$$P_I^* = \frac{1}{2}\left[\frac{C}{D} + 1 \pm \sqrt{\left(\frac{C}{D}\right)^2 - 2\frac{C}{D} + \frac{11}{3}}\right]$$

As only the smaller root satisfies the second order conditions for a maximum and firm B's maximization problems yield the same quadratic equation, the equilibrium price of a system under incompatibility is :

$$P_I^* = \frac{1}{2}\left[\frac{C}{D} + 1 - \sqrt{\left(\frac{C}{D}\right)^2 - 2\frac{C}{D} + \frac{11}{3}}\right] \qquad (6)$$

P_I^* is positive for $\frac{C}{D} > \frac{2}{3}$, which is always satisfied when the whole market is served.

2.Compatibility

A consumer located at (g_1, g_2) purchases component i from firm A if and only if :

$$P_{iA} + g_i \leq P_{iB} + 1 - g_i \quad \text{or,}$$

$$g_i \leq \frac{P_{iB} - P_{iA} + 1}{2} = T_i$$

This outlines four areas in the unit square (see

figure # 3).

-In square AA, $g_1 \leq T_1$ and $g_2 \leq T_2$ so that consumers choose to buy both components from firm A.

-In square AB, $g_1 \leq T_1$ and $g_2 \geq T_2$ so that consumers buy the first good from A and the second good from B.

-In square BA, $g_1 \geq T_1$ but $g_2 \leq T_2$ so that consumers buy the first good from B and the second good from B.

-In square BB. $g_1 \geq T_1$ and $g_2 \geq T_2$ so that consumers buy both components from firm B.

Firm A's profit function can therefore be written as :

$$\pi_a = [P_{1A} + P_{2A}] \int_C^{T_1} \int_0^{T_2} [C - D(P_{1A}+P_{2A}+g_1+g_2)]dg_2\, dg_1 +$$

$$P_{1A} \int_0^{T_1} \int_{X_2}^{1} [C - D(P_{1A}+P_{2B}+g_1+1-g_2)]dg_2\, dg_1 +$$

$$P_{2A} \int_{T_1}^{1} \int_0^{T_2} [C - D(P_{1B}+P_{2A}+1-g_1+g_2)]dg_2\, dg_1 \qquad (7)$$

Maximizing (7) with respect to P_{1A} and P_{2A}, and imposing symmetry(i.e $P_{1A}=P_{1B}=P_{2A}=P_{2B}=P$) in the first order conditions, one obtains :

$$DP^2 - [\frac{C}{2} + \frac{13}{8}D]\, P + [\frac{C}{2} - \frac{D}{4}] = 0$$

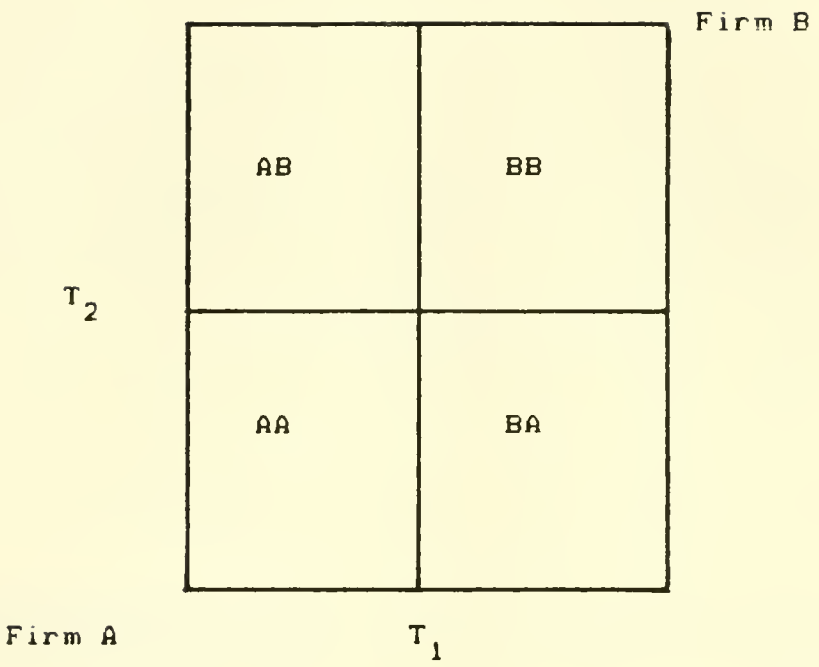


figure # 3

where P is the price of any component. The price of the system under compatibility ($P_c = 2P$) is therefore determined by :

$$DP_c^2 - [C + \frac{13}{4}D]P_c + [2C - D] = 0 \qquad (8)$$

Again, only the smaller root of (8) satisfies the second order conditions for a maximum so that the equilibrium price of the systems is :

$$P_c^* = \frac{1}{2}\left[\frac{C}{D} + \frac{13}{4} - \sqrt{\left(\frac{C}{D}\right)^2 - \frac{3}{2}\frac{C}{D} + \frac{233}{16}}\right] \qquad (9)$$

P_c^* is positive for $\frac{C}{D} > \frac{1}{2}$, which holds when the whole market is served.

III PROFIT RANKINGS

Comparing (7) and (9), it can be seen that

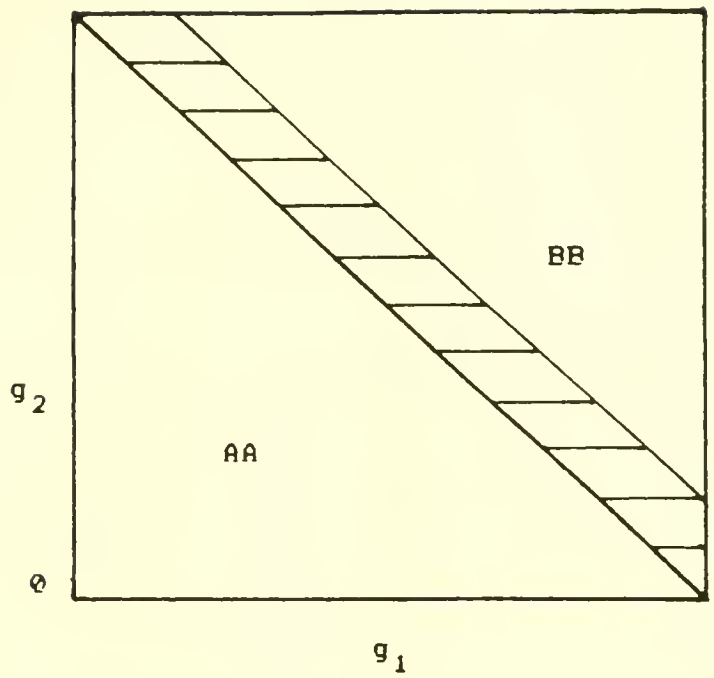
$$P_c^* \geq P_I^* \text{ for all } \frac{C}{D} > 0$$

i.e the two firms charge higher prices for their products when they sell compatible components than when they sell incompatible systems. This is the result of two effects.

First, the 'average distance travelled by customers'

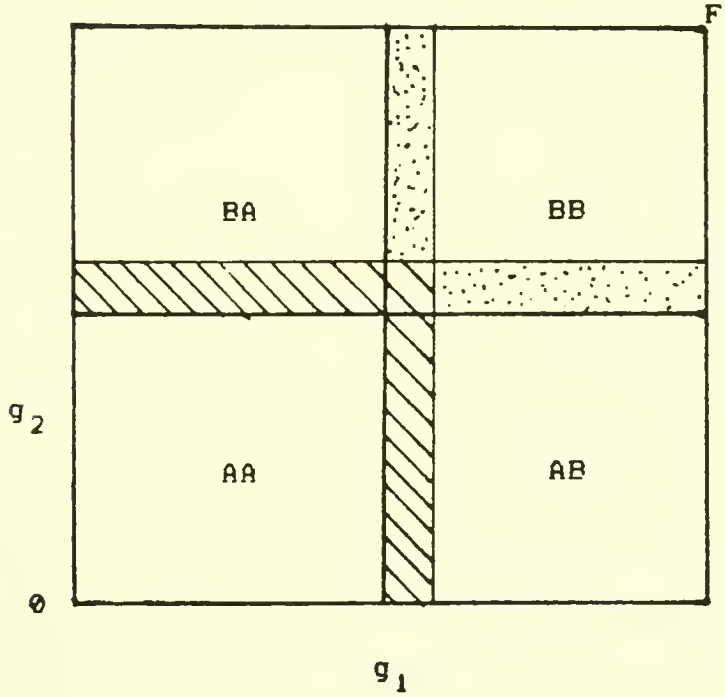
is smaller under compatibility, falling from $\frac{3}{4}$ under incompatibility to $\frac{1}{2}$. Moreover, the 'distance travelled' decreases for consumers located in the areas AB and BA and stays the same for consumers located in AA or BB. This implies that every individual demand function either shifts upwards[6] or is unchanged.

Second, the two firms tend to behave less aggressively when they produce compatible components than when they sell incompatible systems. Figure #4 shows the areas captured by a similar price cut by firm A under incompatibility and under compatibility. The shaded areas are fully appropriated by firm A while dotted areas are shared by A and B. In the absence of compatibility, any price cut by firm i increases its market share to the detriment of its rival. With compatibility, a decrease in the price of firm i's components increases firm i's market share not only by displacing the other firm's sales but also by displacing some of its own sales : cutting the price of one component will increase the sales of all the systems which include this component, i.e the system made of the two components produced by the price cutting firm and the system made of one component of each firm. In other words, under incompatibility firm i captures the full benefits of its price cut , while, with compatibility, some of these benefits are reaped by its rival. It follows that the incentive to cut price is weaker when the firms produce compatible goods.



INCOMPATIBILITY

FIGURE # 4



COMPATIBILITY

The two firms' profits are also larger when compatible products are sold. This is easily shown by noting that the firms' profit functions can be written as:

$$\pi_I^i(P_I) = P_I\left[\frac{C-DP_I}{2} - \frac{D}{3}\right] \quad \text{with } i = A, B$$

$$\pi_C^i(P_C) = P_C\left[\frac{C-DP_C}{2} - \frac{D}{4}\right] \quad \text{with } i = A, B$$

Since $P_C^* \geq P_I^*$ and $P_C^* \leq \frac{C}{2D}$, it must be the case that :

$$\pi_C^i(P_C^*) \geq \pi_I^i(P_I^*)$$

Defining C_A as the cost of building adaptors to make a firm's components compatible with its rival's, and C_c the cost to a firm of choosing the 'common knowledge' technology rather than its own, we have the following SPNEs.

1. In the adaptor case, compatibility arises as the unique equilibrium outcome if and only if $\Pi_C^* - \Pi_I^* \geq C_A$. More precisely, there are three SPNEs. In two of them, one firm's equilibrium strategy is 'compatibility', while the other firm's equilibrium strategy is 'incompatibility'. In the third equilibrium, both firms build adaptors. This last equilibrium is of course Pareto inferior to the other

two.

2. In the consensus case, both compatibility and incompatibility can arise as equilibrium outcomes.

If $\Pi_C^* - \Pi_I^* \leq C_c$, there is a unique SPNE where each firm chooses its own technology.

If $\Pi_C^* - \Pi_I^* \geq C_c$, then there are two SPNE in pure strategies, one where both firms adopt the common technology and one where both firms choose their own incompatible standard. However, both firms would be better off in the compatibility equilibrium[7].

IV. WELFARE

Compatibility has two opposing effects on consumer surplus. On one hand, the prices charged by the firms increase with compatibility, but, on the other hand, the average 'distance' travelled by consumers decreases from $\frac{3}{4}$ to $\frac{1}{2}$. The first effect decreases consumer surplus while the second effect tends to increase it.

While it is not in general possible to determine the impact of compatibility on global welfare, it is worth noticing that all individuals will not be affected equally. Going back to figure # 3, it is clear that consumers located in regions AA and BB experience a decrease in their welfare since they buy the same systems as with incompatibility(i.e. they 'travel' the same distance) but

are charged a higher price. The fortune of the consumers located in the AB and BA areas is unclear. On the one hand, they get closer to their ideal system specifications(by as much as 1 for an individual located at (0,1)) but, on the other hand, they have to pay a higher price. As $P_C^* - P_I^*$ is always smaller than 1 however, some consumers are always made better off by a move from incompatibility to compatibility.

The net effect of compatibility on consumer surplus and social surplus will be derived in the next section for the simpler case where consumers have zero-one demands.

V. MARKET INCOMPLETELY SERVED

In the previous sections, it was assumed that the two firms were direct competitors, i.e. that the whole market was served and that the two firms actively competed for customers at their market boundaries. However, this is only verified if, at the equilibrium prices, the consumer who has to 'travel the largest distance' derives a positive surplus from buying either good, i.e if

$$C - D(P^* + d_1 + d_2) > 0 \text{ when } d_1 + d_2 = 1$$

This condition is satisfied for both the compatibility and the incompatibility[8] equilibria if and only if $\frac{C}{D} > \frac{13}{9}$.

For $\frac{C}{D} < \frac{13}{9}$ however, the two firms are not directly competing with each other and their behavior will differ from the one described earlier.

As a matter of convenience, we shall assume in this section that consumers have zero/one demands. A consumer located at a distance $d_1 + d_2$ of a system sold at a price P obtains a surplus of $C-P-\lambda(d_1+d_2)$ when purchasing one unit of the system. λ measures the amount of product differentiation between the two firms' components. The closer λ is to zero, the closer substitutes the two firms products are. Each consumer buys one unit of the system which yields the greater surplus, provided that this surplus is positive. Depending on the level of the reservation price C, different types of equilibria emerge. They are presented in table I. where P^* represents the equilibrium price of a system, Π^* the profit of each firm, CS^* and SS^* the equilibrium consumer and social surpluses, AS^* the market area served by both firms and D^* the 'average distance' travelled by the consumers who actually buy one unit of a system. All these variables are displayed as a function of C in figure # 5. Sketches of the derivations are provided in appendix B.

For low reservation prices (i.e. for $C < \frac{5}{6}\lambda$), the two firms are 'local monopolists' both in the compatibility and in the incompatibility equilibria (Figure # 6 a). As in the previous sections, compatibility yields higher prices and profits than incompatibility. This is the result of

two effects similar to the ones discussed in section 3. First, compatibility increases the variety of systems available so that at any given price the number of consumers served will be larger than with incompatibility. This does not imply that, in equilibrium, a greater area will be served under compatibility since prices are higher. This is the equivalent of the shift in individual demand curves mentioned in the first part of the paper. Second, as before, the firms have less incentives to cut prices when they produce compatible components than when they sell incompatible systems[9]. However, as it will be shown at the end of this section, the consequences of this difference in price-cutting incentives are not quite the same as when the whole market is served.

With compatibility, consumers are hurt by higher prices but gain from an increase in the variety of systems available(i.e. $D_c^* < D_i^*$) and from an increase in the market area served. Some consumers who would not be served with incompatibility are better off with compatibility, while consumers who would buy a system under both regimes are worse off in a compatible industry. Total consumer surplus however is higher when firms produce compatible components. As compatibility increases both consumer surplus and profits it also yields a higher social surplus and, in this restricted sense, can be said to be socially superior to incompatibility.

For higher reservation prices (i.e $\frac{5}{6}\lambda < C < \frac{3}{2}\lambda$), the

TABLE 0.1

c	INCOMPATIBILITY	COMPATIBILITY
$0 < c < \frac{3}{2}\lambda$	Local Monopolists $p_1^o = \frac{c}{3}$ $\quad \pi_1^o = \frac{2c^2}{27\lambda^2}$ $CS_1^o = \frac{8c^3}{81\lambda^2}$	Local Monopolists $p_0^o = \frac{2c}{3}$ $\quad \pi_0^o = \frac{16c^3}{1215\lambda^2}$ $\quad CS_0^o = \frac{16c^3}{1215\lambda^2}$ $SS_0^o = \frac{31c^3}{1215\lambda^2}$ $\quad AS_0^o = \frac{16c^2}{243\lambda^2}$ $D_0^o = \frac{c}{81}$
$\frac{3}{2}\lambda < c < \frac{3}{4}\lambda$	$SS_1^o = \frac{29c^3}{81\lambda^2}$ $AS_1^o = \frac{8c^2}{9\lambda^2}$ $\quad D_1^o = \frac{8c}{81}$	Competitors, Partial Service $p_c^o = \frac{1}{8}\left[6c - \frac{13}{2}\lambda + \sqrt{\left(6c - \frac{13}{2}\lambda\right)^2 + 32\left(2\lambda c - \lambda^2 - c^2\right)}\right]$
$\frac{3}{4}\lambda < c < 2\lambda$	Adjacent markets $p_1^o = c - \lambda$ $\quad \pi_1^o = \frac{c-\lambda}{2}$ $CS_1^o = \frac{\lambda}{9}$ $\quad SS_1^o = c - \frac{3\lambda}{2}$ $AS_1^o = 1$ $\quad D_1^o = \frac{2}{9}$	$\pi_0^o = \frac{p_c^o}{9}\left[1 - 8\left(1 + \frac{p_c^o - c}{\lambda}\right)^2\right]$ $CS_c^o = E\left[2c - \frac{2c^2}{\lambda} + \frac{8c\frac{\partial p_0^o}{\partial c}}{\lambda} - 6p_c^o - \frac{\lambda}{2} - 8\frac{p_c^{o2}}{\lambda}\right] - \lambda E^2$ $- \frac{2\lambda}{3} E^3 + \frac{\lambda}{12} \cdot \frac{(c - 2p_c^o)^3}{\lambda}$ with $E = \frac{1}{\lambda}(c - 2p_0^o) - \frac{1}{2}$

$2\lambda < C < 3\lambda$

Direct Competitors

$$P_1^* = \lambda$$

$$\Pi_1^* = \frac{\lambda}{2}$$

$$CS_1^* = C - \frac{5}{3}\lambda$$

$$SS_1^* = C - \frac{2}{3}\lambda$$

$$AS_1^* = 1$$

$$D_1^* = \frac{2}{3}$$

$3\lambda < C$

$$SS_c^* = 2\Pi_c^* + CS_o^*$$

$$AS_c^* = 1 - 2\left(1 - C + \frac{P_c^*}{\lambda}\right)^2$$

Direct Competitors, Full Service

$$P_c^* = 2\lambda$$

$$\Pi_c^* = 1\lambda$$

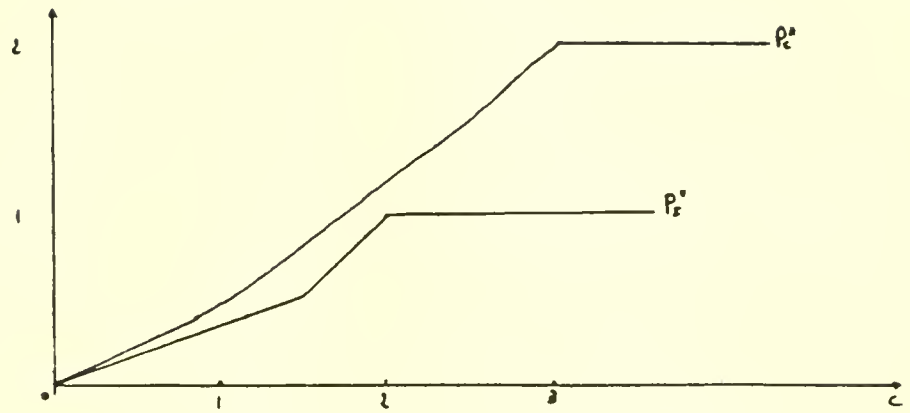
$$CS_c^* = C - \frac{5}{2}\lambda$$

$$SS_c^* = C - \frac{\lambda}{2}$$

$$AS_c^* = 1$$

$$D_c^* = \frac{1}{2}$$

PRICE OF A SYSTEM ($\lambda = 1$)



PROFITS ($\lambda = 1$)

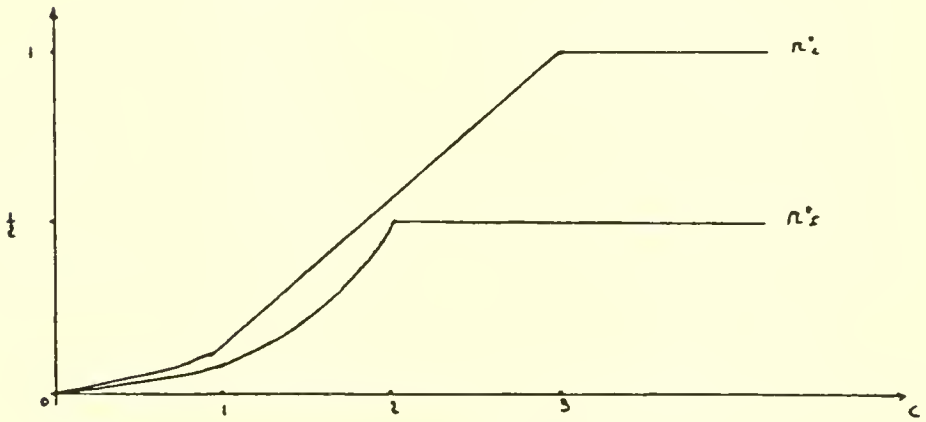
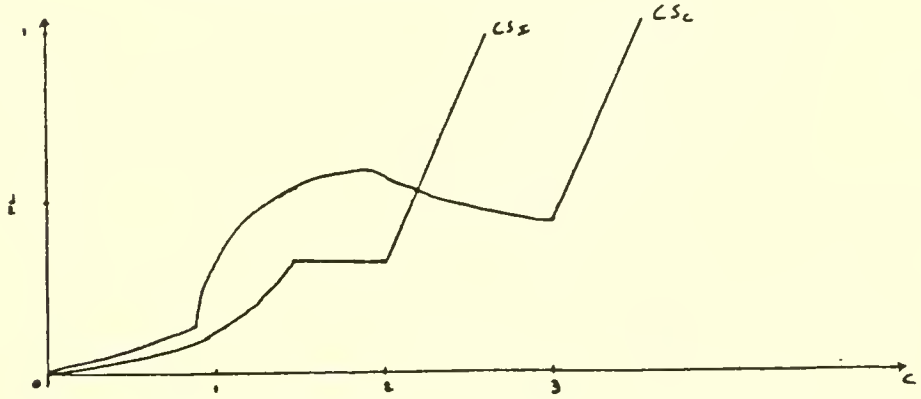
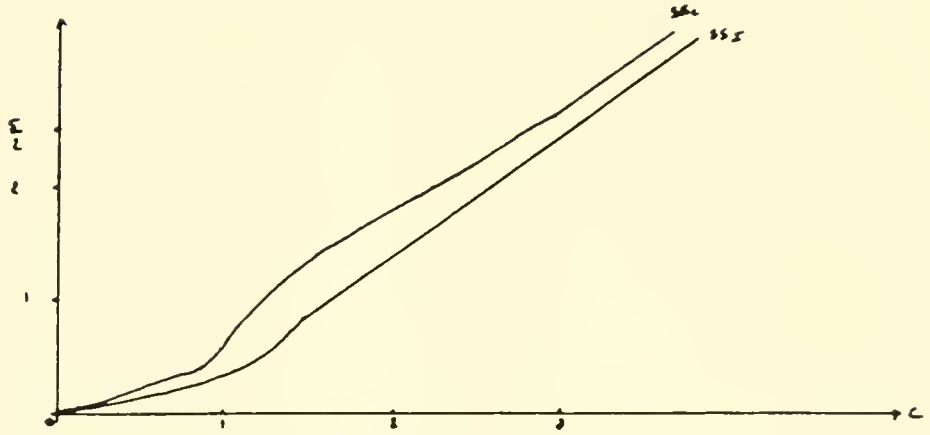


FIGURE # 5

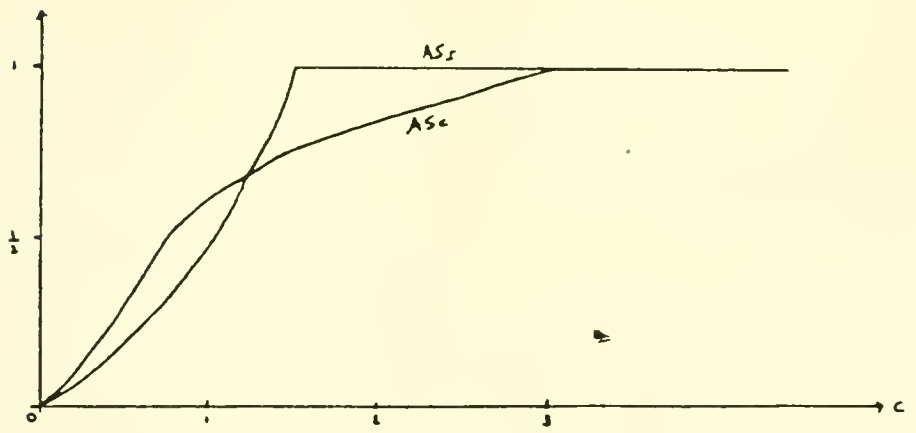
CONSUMER SURPLUS ($\lambda = 1$)



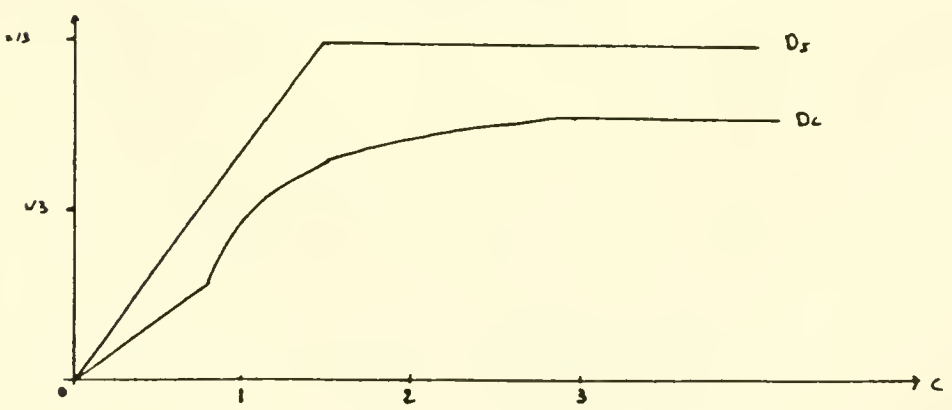
SOCIAL SURPLUS ($\lambda = 1$)



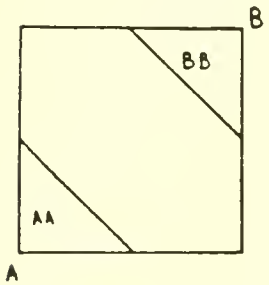
AREA SERVED ($\lambda = 1$)



AVERAGE DISTANCE ($\lambda = 1$)



INCOMPATIBILITY



COMPATIBILITY

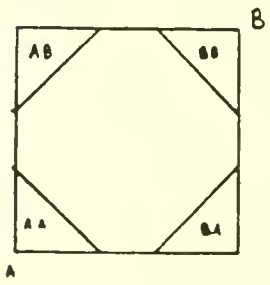
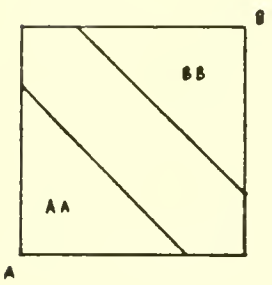


FIGURE # 6 a



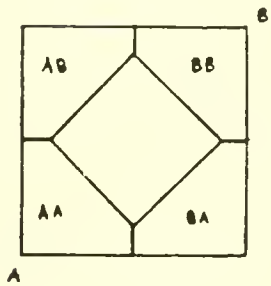
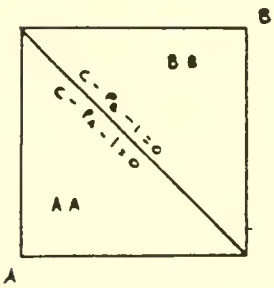


FIGURE # 6 b



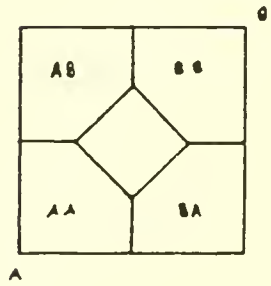
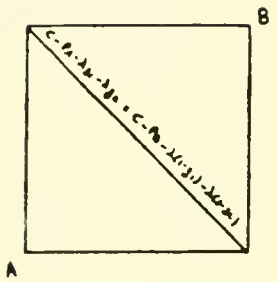


FIGURE # 6 c



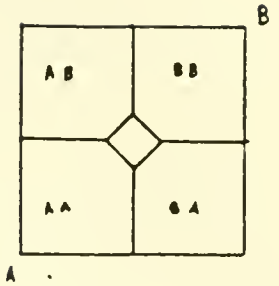
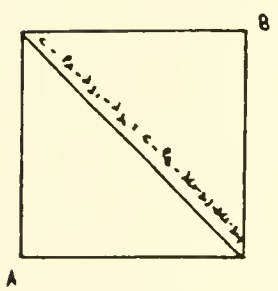


FIGURE # 6 d



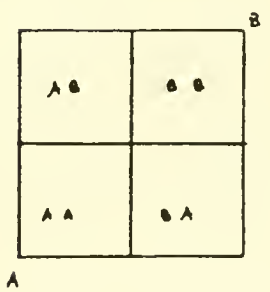


FIGURE # 6 e

two firms are still local monopolists if they produce incompatible components, while they would be direct competitors in a standardization equilibrium, so that the nature of competition is no longer the same in the compatibility and incompatibility equilibria. The impact of this discrepancy on equilibrium prices and profits is analyzed at the end of this section. In both cases, some consumers are not served (Figure # 6 b). The rankings are the same as for $C < \frac{5}{6}\lambda$, with one difference: for $C > 1.25\lambda$, the market area served at equilibrium prices is larger without compatibility.

For intermediate reservation prices (i.e. $\frac{3}{2}\lambda < C < 2\lambda$), the type of compatibility equilibrium is unchanged, while firms producing incompatible components share the whole market but without competing directly[10] (Figure # 6 c). Again, prices and profits are higher with compatibility. A move from incompatibility to compatibility increases the variety of systems available to customers but it raises their price and increases the proportion of consumers which are not served. The first effect dominates and consumer surplus is larger with compatibility. Still, some consumers are worse off when firms produce compatible components (e.g. the consumer located at (0,0)).

For C greater than 2λ the two firms are always direct competitors. In the absence of compatibility, the whole market is served, while some customers choose not to buy in the compatibility equilibrium as long as C is smaller than

3λ (Figure # 6 d). The rankings are the same as in the last case, with one difference : for $C > 2.2\lambda$, consumer surplus is now lower with compatibility. Still, compatibility increases social surplus.

Finally, for large reservation prices (i.e $C > 3\lambda$), the firms are direct competitors and the whole market is served in both cases. As in section 1 through 4, the prices and profits are higher with compatibility. Here however, this only results from the firms' less agressive behavior in the compatibility equilibrium since, with zero/one demands and the whole market served, an increase in the variety of systems available does not increase demand as it did in section 1 through 4[11]. As for lower values of A, consumer surplus is lower and social surplus is higher when firms sell compatible components.

The previous results hold for any positive amount of product differentiation. As λ decreases, the whole market is served for lower values of C until, for homogenous products, $C > 3\lambda = 0$ becomes the only relevant case.

Although social surplus is always larger with compatibility, it does not follow that the firms' choice of standard is always socially optimal. Socially suboptimal outcomes can occur for two reasons.

First, when a consensus is required to achieve compatibility, we have seen that there are two equilibria in pure strategies, one of them leading to an incompatible industry, even though social surplus is lower without

compatibility.

Second, the social surplus reported in table I is gross of standardization costs. If these costs are taken into account, suboptimality <u>can</u> arise whenever compatibility lovers consumer surplus:

1. Consensus case

Compatibility is an equilibrium outcome if and only if

$$\Pi_C^* - \Pi_I^* \geq C_c \text{ for both firms.}$$

as both firms are identical, this is equivalent to

$$2\Pi_C^* - 2C_c \geq 2\Pi_I^*$$

so that, if $CS_c > CS_I$ then $CS_c + 2\Pi_c - 2C_c \geq CS_I + 2\Pi_I$, and compatibility is the socially optimal outcome.

If $CS_c < CS_I$ however, we could have

$$2\Pi_c - 2\,C_c + CS_c < CS_I + 2\,\Pi_I$$

even if $SS_c = 2\Pi_c + CS_c$ is larger than $SS_I = 2\Pi_I + CS_I$ and if $\Pi_C^* - \Pi_I^* \geq C_c$, i.e. compatibility can be socially suboptimal even if it is an equilibrium outcome and it maximizes social surplus gross of standardization costs. This would for example happen with $\lambda = 1$, $C = 3$ and $C_c = \frac{1}{4}$.

2. Adaptor Case

Compatibility is an equilibrium outcome if and only if $\Pi_C^* - \Pi_I^*$ is greater than C_A for at least one firm. In the

two 'efficient' equilibria, i.e when only one firm builds adaptors, the net social surplus is $CS_c + 2\Pi_c^* - C_A$ so that $CS_c > CS_I$ is a sufficient condition for the compatible equilibrium to be socially optimal. If $CS_c < CS_I$ however, the net social surplus might be lower under compatibility even though the gross social surplus is higher and compatibility is the unique equilibrium outcome. The same reasoning applies to the 'inefficient' equilibrium, where both firms build adaptors , the net social surplus being equal to $CS_c + 2\Pi_c^* - 2C_A$.

As CS_c is smaller than CS_I for large values of C, we can conclude that for high reservation prices and high (but not prohibitive) costs of achieving compatibility, compatibility is the equilibrium outcome of the game, even though incompatibility would be socially preferrable. This occurs for example with $\lambda = 1$, $C = 4$ and $C_c = \frac{1}{3}$. There can thus be a tendency towards excessive standardization.

VI ALTERNATIVE INTERPRETATION AND MARKET STRUCTURE

The results obtained in the last section can be explained by the conbination of three effects :

1. Compatibility increases the variety of systems available ,thereby increasing industry demand.
2. As explained in previous sections, the

firms have less incentives to cut price when standardization prevails.

3. The degree of competition between the different systems available can be affected by the firms' compatibility decisions.

Let us abstract for a moment from the 'variety-increasing' effect of compatibility and relate the impact of standardization on the firms' price-cutting incentives to the theory of multiproduct firms.

In our model, each firm sells two complementary goods. If two such goods are sold by a monopolists, it is well known that their prices will be lower than if each good were sold by a separate firm. This is so because the multiproduct monopolist realizes that cutting the price of one component increases the demand for its two goods. In other words, the multiproduct firm internalizes the complementarity links between the two products while two single-product firms do not. Consequently, under similar cost conditions, the profits of the multiproduct firm are higher than the sum of the profits that would be obtained by two single-good sellers.

In a sense our results are just an application of this principle since, as argued in earlier sections, firms internalize the complementarity effects more fully when their systems are incompatible than when compatibility prevails. When the two firms are local monopolists, it

follows that prices are lower without compatibility. Moreover, the profits of a compatible industry are less than twice[12] the profits of an incompatible industry, meaning that 'full internalization' of complementarity effects does indeed increase profits when the firms do not compete directly.

When firms are direct competitors however, this analysis no longer holds. It is still true that, due to a greater internalization of complementarity links, each firm will set lower prices under incompatibility for any given level of its rival's prices. However, as the firms' reaction functions are now increasing in their rival's prices, such a behavior drives the equilibrium prices farther down, hurting profits. This becomes especially clear as soon as the whole market is served as the increased price-cutting incentives drives the equilibrium prices down without increasing the firms' equilibrium market shares : the monopolists' blessing has turned into a curse for the full competitors.

This analysis suggests that our results depend heavily on the assumption that each firm sells a full set of components. This is confirmed by a comparison of table I with table II where the two integrated firms have been replaced by four independent single-good producers and where 'incompatibility' refers to an industry where only two different 'systems' can be assembled. With such an industry structure, there is not any difference in the

TABLE II: FOUR INDEPENDENT FIRMS

C	INCOMPATIBILITY	COMPATIBILITY
$C \leq \lambda$	$P_I^* = \frac{C}{2}$ $\Pi_I^* = \frac{C^3}{32\lambda^2}$	$P_C^* = \frac{C}{2}$ $\Pi_C^* = \frac{C^3}{32\lambda^2}$
$\lambda \leq C \leq 2\lambda$		$P_i^* = \frac{10C - 11\lambda + \sqrt{7\lambda^2 - 28\lambda C + 4C^2}}{24}$ Simulations C P_C^* Π_C^* Π_I^* $\frac{3\lambda}{2}$ $.86\lambda$ $.295\lambda$ $.106\lambda$ 2λ 1.228λ $.447\lambda$ $.25\lambda$ $\frac{9\lambda}{4}$ 1.4166λ $.472\lambda$ $.312\lambda$ $\frac{5\lambda}{2}$ 1.608λ $.4888\lambda$ $.375\lambda$ $\frac{11\lambda}{4}$ 1.802λ $.4974\lambda$ $.438\lambda$
$2\lambda \leq C \leq 3\lambda$	$P_I^* = C - \lambda$ $\Pi_I^* = \frac{C-\lambda}{4}$	
$C \geq 3\lambda$	$P_I^* = 2\lambda$ $\Pi_I^* = \frac{\lambda}{2}$	$P_C^* = 2\lambda$ $\Pi_C^* = \frac{\lambda}{2}$

degree of internalization of complementarity links in the compatibility and incompatibility equilibria since the firms always ignore these effects. The only impact of standardization is to increase variety, augmenting the market area served at any given prices. It follows that, as long as it does not change the nature of competition (i.e. as long as local monopolies or full competiton emerge in both subgames), the compatibility decision does not have any effect on equilibrium prices and that the ratio between industry profits with and without compatibility goes from two to one as the reservation price increases. As prices are unchanged, standardization increases consumer surplus and thus social surplus(net or gross of standardization costs) as long as the whole market is not served. For intermediate values of the reservation price however the standardization decision does effect the nature of competition in the
last stage of the game since direct competition between systems arise more rapidly in a compatible industry. This third effect explains why, even with four single-product firm, equilibrium prices can be higher when standardization prevails. When systems compete with each other, a given price cut captures a lesser amount of new consumers than when each system enjoys a local monopoly because some of the consumers to be captured could get some positive consumer surplus by buying another system. It follows that, for intermediate reservation prices (i.e. $\lambda \leq C \leq 3\lambda$),

the firms incentives to cut prices are lower, and thus equilibrium prices are higher in a compatible industry.

VII PARTIAL COMPATIBILITY

In the two-stage game, it was assumed that the firms' only possible choices were incompatibility and full compatibility. However, it might also be possible for a firm to choose partial compatibility, i.e to make its first component, for example, compatible with the other firm's second component, without making its second good compatible with its rival's first good: some manufacturers ' razor blades fit other firms' razors while their own razors are not compatible with other blades. However, examples of such designs are rare, which suggests that partial compatibility might usually be a dominated strategy.

The four possible situations are illustrated in figure # 7. If X_{1A} is compatible with X_{2B} but X_{1B} is not compatible with X_{2A}, the consumers must choose between three systems : X_{AA}, X_{AB} and X_{BB}, so that the unit square will be divided as in figure # 8. Comparing figure # 8 to figures # 2 and # 3, shows that partial compatibility is an intermediate case both in terms of 'average distance travelled' and in terms of aggressivity. This is confirmed by the results shown in table #3. For all positive reservation prices, partial compatibility yields profits

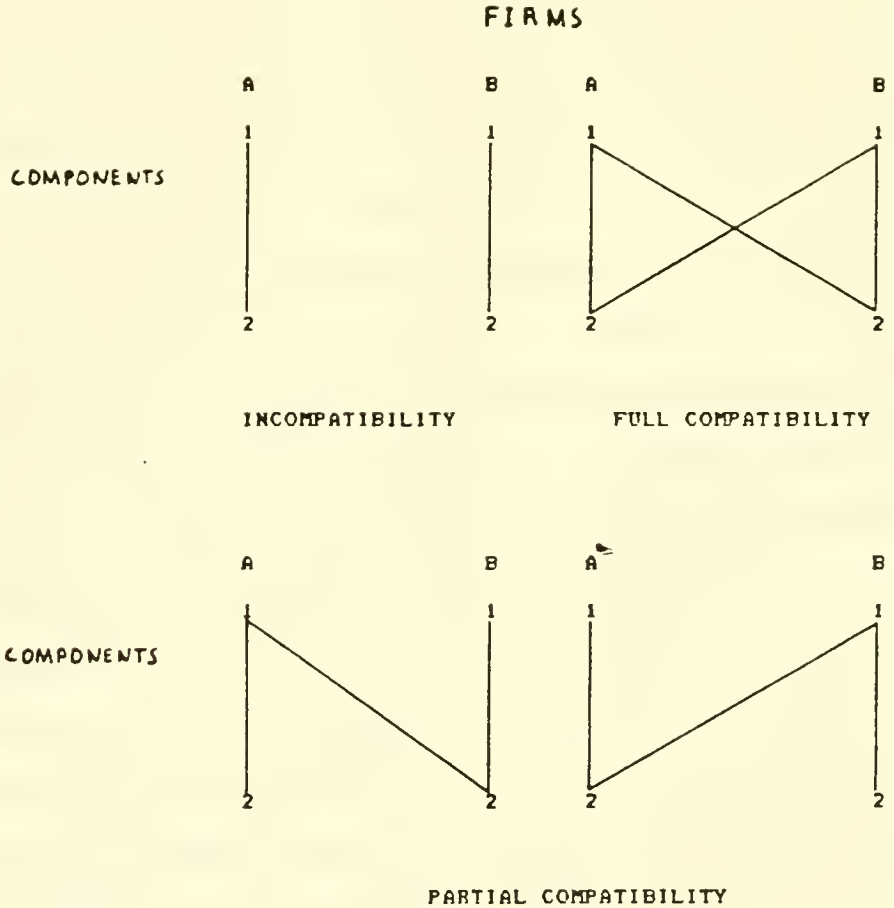

FIRMS
A
B
A
B
1
1
1
1
COMPONENTS
2
2
2
2
INCOMPATIBILITY
FULL COMPATIBILITY
A
B
A
B
1
1
1
1
COMPONENTS
2
2
2
2
PARTIAL COMPATIBILITY

FIGURE # 7

TABLE III

Local Monopolists

$C < \frac{6}{7}\lambda$

$P_{1A}^* = P_{2B}^* = \frac{C}{4}$ $\qquad$ $P_{2A}^* = P_{1B}^* = \frac{C}{12}$

$\Pi^* = \frac{91C^3}{864\lambda^2}$ $\qquad$ $CS^* = \frac{8C^3}{81\lambda^2} + \frac{C^3}{96\lambda^2}$

Competitors, Not Whole Market Served

$P_{1A}^* = P_{2B}^* = P$ and $P_{1B}^* = P_{2A}^* = Q$ are determined by:

$$-P^2 - 2Q^2 - 9PQ + 4PC - 10\lambda P + 6QC - 3\lambda Q - 2C^2 - \lambda^2 + 4\lambda C = 0$$

$$-11P^2 + 9Q^2 + 2PQ + 2PC - 8\lambda P - 8QC - 4\lambda Q - \lambda^2 + 4\lambda C = 0$$

$\frac{6}{7} < C < 2.2\lambda$

C	P	Q	Π
1	.19	.14	.0796
1.5	.27	.21	.252

Whole Market Served

$2.2\lambda < C$	$P^*_{1A} = P^*_{2B} = .8215\lambda$	$P^*_{1B} = P^*_{2A} = .3214$
	$\Pi^* = .587\lambda$	$CS^* = C - 1.797\lambda$

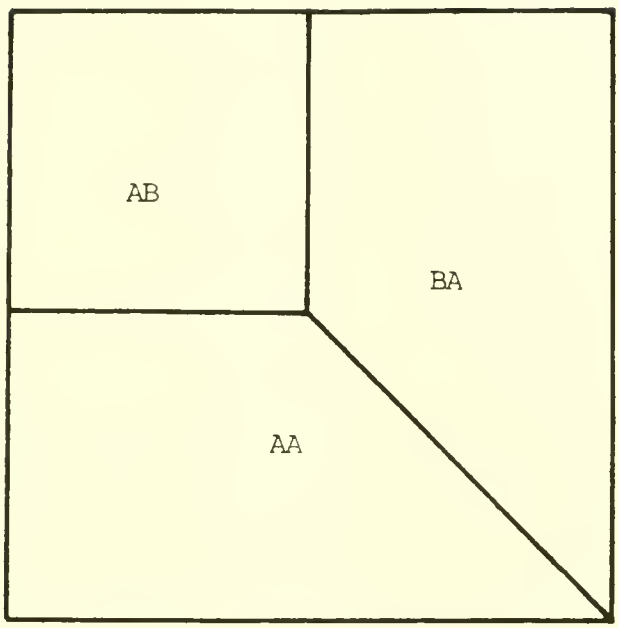


FIGURE 8

which are higher than with incompatibility but lower than with full compatibility and is thus a dominated strategy. The equilibrium price of the compatible component is higher than the price of the incompatible component, reflecting the by now familiar difference in price cutting incentives : the firm fully appropriates the benefits from a cut in the price of its incompatible component, while the benefits from a cut in the price of its compatible components are shared with its rival.

VIII BUNDLING

In our analysis so far, firms were only allowed to set the price of each of their components. However, it is commonly observed that multiproduct firms tend to offer discounts to customers who purchase several elements of their product line. This type of behavior can be captured by allowing the firms to charge a price $P_i < P_{1i} + P_{2i}$ ($i = A,B$) to consumers who choose to buy the whole system from the same firm. This yields a three stage game where the firms first determine their standards, then choose whether or not to offer discounts on their complete systems, before finally competing on prices[13].

It will be assumed throughout that the firms can actually charge a lower price for their 'bundle' than for the sum of their two separate components, i.e. arbitrage

('debundling') is ruled out.

The first thing to notice is that the opportunity to bundle does not affect the results when components are not compatible across firms since the consumers would never want to buy separate elements anyway. If compatibility prevails however, bundling will significantly effect price competition between the two firms in the last stage of the game.

In order to keep the computations manageable, we will only consider the two extreme cases of local monopolies and direct competition with the whole market served. It will be shown that these two polar cases yield rather different outcomes. Finally, it will be assumed, as in section V, that consumers have 'ero/one demands for the system.

1.Local Monopolists

As before, this is the case where the markets area served by different systems do not touch .

If there is compatibility and both firms choose to bundle, then firm i's maximization problem is :

$$\underset{P_{1i},P_{2i},P_i}{MAX} \quad \frac{P_i[C-P_i]^2}{2\lambda^2} + \frac{P_{1i}[C-P_{1i}-P_{2j}]^2}{2\lambda^2} + \frac{P_{2i}[C-P_{1j}-P_{2i}]^2}{2\lambda^2}$$

where $j,i = A,B \quad i \neq j$ and P_i is the price charged for firm i's complete system. The first order

conditions of this problem can be solved for:

$$P_i^* = \frac{C}{3}$$

$$P_{1i} = P_{2i} = \frac{C}{4}$$

so that:

$$\Pi_i^* = \frac{59C^3}{432\lambda^2}$$

If only one firm (e.g. firm A) chooses to bundle, then its maximization problem is the same as above while the non-bundling firm solves:

$$\underset{P_{1B}, P_{2B}}{MAX} \quad \frac{P_{1B}[C-P_{1B}-P_{2A}]^2}{2\lambda^2} + \frac{P_{2B}[C-P_{1A}-P_{2B}]^2}{2\lambda^2} + [P_{1B}+P_{2B}]\frac{[C-P_{1B}-P_{2B}]^2}{}$$

so that :

$$P_A^* = \frac{C}{3}$$

$$P_{1A}^* = P_{2A}^* = \frac{26 + \sqrt{56}}{124} C \simeq 0.27\ C$$

$$P_{1B} = P_{2B}^* = \frac{46 - 3\sqrt{56}}{124} C \simeq 0.09\ C$$

$$\Pi_A^* \simeq 0.185\ \frac{C^3}{\lambda^2}$$

$$\Pi_B^* \simeq 0.0965\ \frac{C^3}{\lambda^2}$$

Comparing these results to those obtained without bundling (table I), it appears that :

$$\Pi^*_{BN} > \Pi^*_{NN} > \Pi^*_{BB} > \Pi^*_{NB}$$

where Π^*_{BN} is a firm's profit when it chooses to bundle while its rival does not offer a discount on its complete system. Similarly, Π^*_{NN} is a firm's profit when neither firm "bundles". The rest of the notation is straightforward.

This is a prisonner's dilemma : both firms will choose to bundle even though they would be better off if they could agree not to bundle.

Given that its rival only sets a price for separate components, a firm increases its profit by bundling because of two effects. First, when selling the bundle, the firm fully internalizes the complementarity links between its two components, which is beneficial in the case of local monopolies. Second, as $P^*_{iA} > P^*_{iB}$, firm A enjoys a 'free ride' at the expense of its rival since the demand for the 'mixed systems' is determined by the sum of the prices of their two components. In other words, A gets a larger share of the revenues from the mixed systems than B. This last effect also explains why Π^*_{NB} is smaller than Π^*_{NN}.

The fact that bundling is also a best response to bundling results from similar effects, i.e. internalization of complementarity effects and avoidance of the 'free rider' phenomenon.

Finally, an equilibrium with bundling yields lower

profits than a situation without bundling. There are two opposing effects involved here. On the one hand, bundling leads the firms to internalize the complementarity links between their components more fully, increasing the profits realized on their own full systems. On the other hand however, the firms charge higher prices than before on their single components (less internalization of complementarity there), decreasing their profits on the 'mixed systems'. This second effect dominates.

In the bundling equilibrium, the expressions for consumer surplus, area served, average distance travelled and social surplus(gross of standardization and bundling costs) are :

$$CS_B^* = \frac{91\ C^3}{648\lambda^2} < CS_C^*$$

$$AS_B^* = \frac{25C^2}{36\lambda^2} < AS_C^*$$

$$D_B^* = \frac{91C}{225\lambda} > D_C^*$$

$$SS_B^* = \frac{67C^3}{137\lambda^2} < SS_C^*$$

so that the bundling equilibrium is socially inferior to the non-bundling equilibrium : the increased number of

buyers of homogenous systems who are served does not compensate for the decrease in the number of buyers of heterogenous systems who are served. Also, more 'distant' buyers of the homogenous systems are served, while buyers of heterogenous systems who are closer to their ideal system specification are neglected.

2. Direct Competitors

When the components are compatible across firms and both firms choose to bundle, their maximization problem is (see Figure #):

$$\underset{P_i, P_{1i}, P_{2i}}{MAX} \frac{P_i}{4\lambda^2} \{[P_{1i}+P_{2j}+\lambda-P_i][P_{1j}+P_{2i}+\lambda-P_i] - [P_{1j}+P_{1i}+P_{2j}+P_{2i}-P_i-P_j]^2\} +$$

$$\frac{P_{1i}}{4\lambda^2}[\lambda+P_i-P_{1i}-P_{2j}][\lambda+P_j-P_{1i}-P_{2j}]$$

$$+ \frac{P_{2i}}{4\lambda^2}[\lambda+P_i-P_{1j}-P_{2i}][\lambda+P_j-P_{1j}-P_{2i}]$$

where $i, j = A, B \quad i \neq j$.

Imposing symmetry in the first order conditions, one gets:

$$P_i^* \simeq 1.667\lambda$$

$$P_{1i}^* = P_{2i}^* \simeq 0.9167\lambda$$

so that:

$$\Pi_i^* \simeq 0.8391\lambda$$

These results hold as long as firms are indeed full competitors at the equilibrium prices, i.e as long as:

$$C \geq 2.667\lambda.$$

If firm A is the only one to bundle, the maximization problems are:

$$\underset{P_A, P_{1A}, P_{2A}}{MAX} \frac{P_A}{4\lambda^2}\left([\lambda+P_{1A}+P_{2B}-P_A][\lambda+P_{1B}+P_{2A}-P_A] - \frac{1}{2}[P_{1A}+P_{2A}-P_a]^2\right)$$

$$+\frac{P_{1A}}{4\lambda^2}[\lambda+P_A-P_{1A}-P_{2B}][\lambda+P_{1B}-P_{1A}]$$

$$+\frac{P_{2A}}{4\lambda^2}[\lambda+P_A-P_{1B}-P_{2A}][\lambda+P_{2B}-P_{2A}]$$

$$\underset{P_{1B}, P_{2B}}{MAX} \frac{P_{1B}+P_{2B}}{4\lambda^2}\left([\lambda+P_{1A}-P_{1B}][\lambda+P_{2A}-P_{2B}]-\frac{1}{2}[P_{1A}+P_{2A}-P_A]^2\right)$$

$$+\frac{P_{1B}}{4\lambda^2}[\lambda+P_A-P_{1B}-P_{2A}][\lambda+P_{2B}-P_{2A}]+\frac{P_{2B}}{4\lambda^2}[\lambda+P_A-P_{1A}-P_{2B}][\lambda+P_{1B}-P_{1A}]$$

Solving the system of first order conditions, one gets:

$$P_A^* \simeq 1.56\lambda$$
$$P_{1A}^* = P_{2A}^* \simeq 1.15\lambda$$
$$P_{1B}^* = P_{2B}^* \simeq 0.79\lambda$$
$$\Pi_A^* \simeq 0.8641\lambda$$
$$\Pi_B^* \simeq 0.7791\lambda$$

Comparing these results to those obtained in the absence of bundling (table 1), it appears that:

$$\Pi_{NN} > \Pi_{BN} > \Pi_{BB} > \Pi_{NB}$$

so that both firms will choose not to bundle, which is indeed the best they can do. That this is in sharp contrast to the results derived for local monopolists should not be surprising given our discussion in section 6. Bundling increases the extent of internalization of the complementarity links between a firm's own components, leading to more price-cutting which can only harm profits since the whole market is served anyway. The fact that $\Pi_{NN} > \Pi_{BN}$ just says that the losses from such harmful price-cutting outweigh the benefits to the bundling firm of the 'free rider' phenomenon described earlier.

If both firms were to bundle, consumer surplus and social surplus(gross of standardization costs) would be given by:

$$CS_B^* \simeq C - 2.272\lambda \quad > CS_C^*$$
$$SS_B^* \simeq C - 0.5938\lambda \quad < SS_C^*$$

As bundling decreases all the equilibrium prices while leaving the number of systems available unchanged, it must increase consumer surplus. However, this is not sufficient to make up for the loss in profits so that non-bundling is socially preferable to bundling.

X. CONCLUSION

We have developed a stylized model where two firms produce two-component systems. The firms have to decide whether or not to make their systems compatible with their rival's before competing on prices. The symmetric perfect Nash equilibrium of this two-stage game has been shown to depend on how compatibility can be achieved. If it can be enforced unilaterally (adaptor case), then product compatibility arises and is always socially optimal provided that there are no costs to achieving standardization. If compatibility requires a consensus however, there are two equilibria in pure strategies, one involving standardization and the other leading to incompatibility.

This, of course, does not mean that standardization

will generally tend to prevail or that it is always desirable. Any cost incurred to achieve compatibility, such as additional research and development expenditures, will reduce the firms' incentives to produce compatible components and should be deducted from the social surplus before making any welfare judgement. It has indeed been shown that if the costs of standardization and the reservation prices are sufficiently high, the firms will tend to choose compatibility even though an incompatible industry would be socially preferable. Also, network externalities, which were left out of our model, are certainly important in many industries and will, other things being held equal, increase the desirability of product standardization. Their impact on the firms' incentives to standardize, as analyzed by Katz and Shapiro(1985), should also be weighted against the incentives identified in this paper before any conclusion is drawn. Finally, the adoption of a common standard by independent firms is an essentially dynamic progress. This dimension, examined by Farrell-Saloner (1985, 1986) and Katz-Shapiro(1986) cannot of course be captured in our purely static model.

We have also argued that, by increasing the number of systems available, product compatibility increases the range of consumers'choice, an apparent contradiction of Farrell and Saloner's claim that product standardization necessarily reduces product differentiation. However. the

two propositions refer to two different aspects of product diversity. On the one hand, product compatibility increases the number of 'systems' among which consumers can choose, but, on the other hand, it might not be technically possible for the firms to produce compatible components without making their products more similar in other respects, i.e without reducing the diversity of similar components produced by different firms. The compatibility which prevails in the home stereo industry increases the number of stereo systems that a consumer can assemble, but it might also have been achieved at the cost of reducing the variety of features displayed by,for example, the tape decks produced by different manufacturers.

Even if one disregards such technical constraints, the degree of product differentiation between similar components might not be independent of whether or not they are compatible across manufacturers. This issue was avoided by assuming that the firms' 'locations' were exogenously determined. An interesting extension would be to allow firms to choose both their 'location' and their price. In the framework of this paper however, familiar non-existence problems would arise (see Gabsiewicz and Thisse for example). We hope to address this issue in a future paper where entry occurs sequentially and involves some sunk cost.

The most significant contribution of this paper might

well be to underline the importance of explicitly modelling 'systems' as combinations of components. Not only does such an approach reveal several effects which had been ignored so far, it is also a necessary first step toward the analysis of more realistic market structures. By treating 'systems' as single goods, one implicitely assumes either that every firm in the industry produces a full line of components or that firms sell a single component to consumers who have already bought the rest of the 'system'. Needless to say, this does not always fit the observed industry patterns. In the computer industry, only a few firms can be said to produce full systems (e.g. IBM); many others produce a single component (software, printers,...) or just a few of them. The same observation holds for the amateur photography industry where Kodak produces films and cameras , while Pentax and Nikon, for example, do not sell films.

Other interesting cases are industries where one firm has a monopoly in the production of one of the components and industries where all the components are mostly produced by single product firms. Only by explicitely recognizing the multicomponent nature of the systems sold can we hope to understand the behavior of the firms operating in these markets[14]. We believe that this is a fruitful direction for future research.

FOOTNOTES

1. It is assumed that there is not any repeat purchase. With repeat purchase, a firm might want to set a low initial price in order for consumers to choose the 'computer' compatible with their product. For an analysis of the case where consumers rationally expect such a pricing strategy, see N.Gallini(1986).
2. Or cannot be used profitably by its rival.
3. The 'location' of the firms is exogenous. The significance of this assumption is discussed in the conclusion.
4. The indirect surplus function of a consumer located at (g_1, g_2) and paying P for the system is :

$$S = \frac{[C - D(P+d_1+d_2)]^2}{2D}$$

and is maximized by choosing the system with the lowest $P + d_1 + d_2$.

5. Alternatively, (3) and (4) could be maximized with respect to the prices of individual components without effecting the results.
6. The intercept of the demand function, $C-D(d_1+d_2)$, increases as d_1+d_2 decreases.
7. Compatibility would be the outcome of the unique

SPNE if the first stage of the game were to be played sequentially.

8. More precisely the necessary and sufficient condition for the whole market to be served at the equilibrium prices are $\frac{C}{D} > \frac{13}{9}$ with compatibility and $\frac{C}{D} > \frac{4}{3}$ with incompatibility.

9. Even when firms are local monopolists, compatibility reduces the firms' price cutting incentives, as shown in appendix C.

10. In the sense that their potential market areas do not overlap, i.e :

$$C - P - 1 = 0$$

11. More precisely, the 'demand effect' disappears as soon as, at the equilibrium prices prevailing under compatibility, producers of incompatible systems would serve the whole market, i.e as soon as:

$$C - P_C^* - \lambda \geq 0$$

12. Without a difference in price-cutting incentive, we would have $\Pi_C^* = 2\,\Pi_I^*$ since, at equal prices, the firms serve an area twicw as large with compatibility.

13. The order of the first two moves is unimportant.

14. Indeed, some of the cases mentioned can be examined by modifying slightly the model presented here. .

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APPENDIX A

Assume that the consumers want to purchase the two components in a proportion of r units of good 1 to 1-r units of good 2. Figure # 8 shows how this affect the areas captured by two firms who sell incompatible systems

As an example, let us examine the case where r is smaller than one half. Firm A's profits are :

$$\pi_A = P_A \int_0^1 \int_0^{X-[r/(1-r)]} [C - D(P_a+g_1+g_2)]dg_2\, dg_1$$

where $X = \frac{P_B - P_A}{4(1-r)}$. The first order condition is :

$$\left[(C-DP_A)X - \frac{D}{2}X^2 - \frac{(C-DP_A)r}{2(1-r)} - \frac{CX(1-2r)}{2(1-r)} + \frac{Cr(2-3r)}{(1-r)^2}\right] +$$

$$P_A\left[-DX - \frac{(C-DP_A)}{4(1-r)} + \frac{DX}{4(1-r)} + \frac{Dr}{2(1-r)} + \frac{D(1-2r)}{8(1-r)^2}\right] \qquad [1]$$

If the two firms produce compatible components, the equilibrium price P_C^* is independent of r.

Substituting values for r into [1] and solving the

resulting quadratic equation for the smaller root it appears that $P_C^* \geq P_I^*$ still holds.

APPENDIX B

I. INCOMPATIBILITY

a. Local monopolist

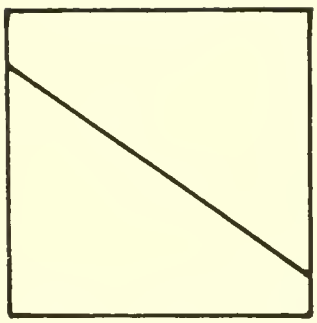
Firm A chooses P_A to maximize $\pi_A = \frac{P_A}{2\lambda^2}(C-P_A)^2$, which yields $P_A = \frac{C}{3}$. For the two firms markets to be disjoint, it must be the case that $C-P_A < \lambda$ or $C < \frac{3}{2}\lambda$. The average distance travelled is given by :

$$\frac{2}{AS_I^*}\int_0^{\frac{2C}{3\lambda}}\int_0^{\frac{2C}{3\lambda}-g_1}(g_1+g_2)\,dg_2\,dg_1$$

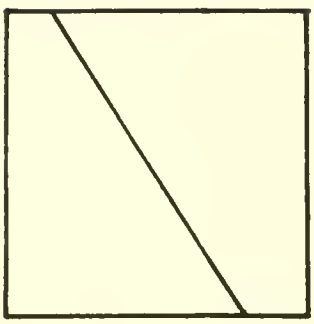
where $AS_I^* = \frac{4C^2}{9\lambda^2}$

b. Adjacent markets

Firm A sets P_A so that its market touches firm B's market : $P_A = 2C - 2\lambda - P_B$. Imposing symmetry yields $P_a^* = C-\lambda$. The consumer surplus and the average distance 'travelled' are obtained in the same way as for direct competitors.



$r \angle 1/2$



$r \angle 1/2$

FIGURE 9

c. Direct competition

$$\pi_A = P_A \int_0^{1+\frac{P_B-P_A}{2\lambda}} \int^{1+\frac{P_B-P_A}{2\lambda}-g_1} dg_2 dg_1$$

Imposing symmetry on the firt order condition yields $P_A^* = \lambda$

The consumer surplus is given by :

$$2 \int_0^1 \int_0^{1-g_1} (C-\lambda-\lambda g_1-\lambda g_2) dg_2 dg_1$$

II. COMPATIBILITY

a. Local monopoly

$$\pi_A = \frac{P_{1A}+P_{2A}}{2\lambda^2} (C-P_{1A}-P_{2A})^2 + \frac{P_{1A}}{2\lambda^2}(A-P_{1A}-P_{2B})^2 +$$

$$\frac{P_{2A}}{2\lambda^2} (A-P_{1A}-P_{2A})^2$$

Imposing symmetry on the first order conditions yields the equilibrium prices. The two firms markets are disjoint at theses prices if and only if $A-P_{1A}-P_{2A} < \frac{\lambda}{2}$ or $A < \frac{5}{6}\lambda$.

The consumer surplus is given by :

$$4\int_0^{\frac{3C}{5\lambda}}\int_0^{\frac{3C}{5\lambda}-g_1}\left(\frac{3C}{5}-\lambda g_1-\lambda g_2\right)\,dg_2dg_1$$

The average distance 'travelled is :

$$\frac{2}{AS_c^*}\int_0^{\frac{3C}{5\lambda}}\int_0^{\frac{3C}{5\lambda}-g_1}(g_1+g_2)\,dg_2dg_1$$

where $AS_c^* = \frac{18\,C^2}{25\lambda^2}$

b. Direct competitors, not whole market served

$$\pi_A = \frac{P_{1A}+P_{2A}}{4}\left[\left[1+\frac{P_{2B}-P_{2A}}{\lambda}\right]\left[1+\frac{P_{1B}-P_{1A}}{\lambda}\right]-2\left[1+\frac{P_{1B}+P_{1A}+P_{2A}+P_{2B}}{2\lambda}\right.\right.$$

$$\left.\left.-\frac{C}{\lambda}\right]^2\right] + \frac{P_{1A}}{4}\left[\left[1+\frac{P_{2A}-P_{2B}}{\lambda}\right]\left[1+\frac{P_{1B}-P_{1A}}{\lambda}\right]-2\left[1+\frac{P_{1B}+P_{1A}+P_{2A}+P_{2B}}{2\lambda}\right.\right.$$

$$\left.\left.-\frac{C}{\lambda}\right]^2\right] + \frac{P_{2A}}{4}\left[\left[1+\frac{P_{1A}-P_{1B}}{\lambda}\right]\left[1+\frac{P_{2B}-P_{2A}}{\lambda}\right]-2\left[1+\frac{P_{1B}+P_{1A}+P_{2A}+P_{2B}}{2\lambda}\right.\right.$$

$$\left.\left.-\frac{C}{\lambda}\right]^2\right]$$

Maximizing π_A with respect to P_{1A} and P_{2A} and using symmetry yields the equilibrium price.

The market is not completely served if and only if $A-P < \lambda$ where P is the equilibrium price of a system. This is equivalent to $A < 3\lambda$. The firms potential markets overlap if and only if $A-P > \frac{\lambda}{2}$, or $A > \frac{5}{6}\lambda$.

The consumer surplus is given by :

$$4\left(\int_0^{\frac{C-P}{\lambda}-\frac{1}{2}}\int_0^{\frac{1}{2}}(C-P-\lambda g_1-\lambda g_2)\,dg_2\,dg_1 + \int_{\frac{C-P}{\lambda}-\frac{1}{2}}^{\frac{1}{2}}\int_0^{\frac{C-P}{\lambda}-g_1}(C-P-\lambda g_1-\lambda g_2)\,dg_1\,dg_2\right)$$

c. Direct competition, whole market served

$$\pi_A = (P_{1A}+P_{2A})\left(\frac{1}{2}+\frac{P_{2B}-P_{2A}}{2\lambda}\right)\left(\frac{1}{2}+\frac{P_B-P_{1A}}{2\lambda}\right) + P_{1A}\left(\frac{1}{2}+\frac{P_{2A}-P_{2B}}{2\lambda}\right)$$

$$\left(\frac{1}{2}+\frac{P_{1B}-P_{1A}}{2\lambda}\right) + P_{2A}\left(\frac{1}{2}+\frac{P_{1A}-P_{1B}}{2\lambda}\right)\left(\frac{1}{2}+\frac{P_{2B}-P_{2A}}{2\lambda}\right)$$

Maximizing with respect to P_{1A} and P_{2A} and imposing symmetry in the first order conditions yield the equilibrium price $P^* = 2\lambda$. At this price, the whole market is served if and only if $A-2\lambda > 1$ or $A > 3\lambda$.

The consumer surplus is given by :

$$\int_0^{\frac{1}{2}}\int_0^{\frac{1}{2}} (C-2\lambda-\lambda g_1-\lambda g_2)\,dg_1\,dg_2$$

III. PARTIAL COMPATIBILITY

Local Monopolists

$$\pi_A = \frac{P_{1A}+P_{2A}}{2}\left[\frac{C-P_{1A}-P_{2A}}{\lambda}\right]2 + \frac{P_{1A}}{2}\left[\frac{C-P_{1A}-P_{2B}}{\lambda}\right]2$$

Setting $P_{1A} = P_{2B} = P$, the price of each firm's compatible component, and $P_{1B} = P_{2A} = Q$ in the first order conditions yields :

$$11P^2 + 3Q^2 + 6PQ - 10PC - 4QC + 2C^2 = 0$$

$$3P^2 + 3Q^2 + 6PQ - 4PC - 4QC + C^2 = 0$$

$$CS = 2\int_0^{\frac{2C}{3\lambda}}\int_0^{\frac{2C}{3\lambda}-g_1}[\tfrac{2C}{3\lambda}-\lambda g_1-\lambda g_2]dg_2dg_1 + \int_0^{\frac{C}{2\lambda}}\int_0^{\frac{C}{2\lambda}-g_1}[\tfrac{C}{2}-\lambda g_1-\lambda g_2]dg_2dg_1$$

Competitors, Not Whole Market Served

$$\pi_A = \frac{P_{1A}+P_{2A}}{2}[X^2-Z^2] + \frac{P_{1A}}{2}[Y^2-Z^2-W^2]$$

where $X = \frac{C-P_{1A}-P_{2A}}{\lambda}$ $Y = \frac{C-P_{1A}-P_{2B}}{\lambda}$ and

$$W = \frac{2C-2P_{1A}-P_{2A}-P_{2B}-\lambda}{2\lambda}$$

Imposing $P_{1A} = P_{2B} = P$ and $P_{1B} = P_{2A} = Q$ in the first order conditions, one gets:

$$-P^2-2Q^2-9PQ+4PC-10\lambda P+6QC-3\lambda Q-2C^2-\lambda^2+4\lambda C = 0$$
$$-11P^2+9Q^2+2PQ+2PC-8\lambda P-8QC-4\lambda Q-\lambda^2+4\lambda C + o$$

Whole Market Served

$$\pi_A = P_{1A}[X(1-Y) + XY + \frac{Y^2}{2}] + P_{2A}[XY + \frac{Y^2}{2}]$$

where $X = \frac{P_{1B}-P_{1A}}{2\lambda} + \frac{1}{2}$ and $Y = \frac{P_{2B}-P_{2A}}{2\lambda} + \frac{1}{2}$

$$CS = 2\int_0^{\frac{1}{4}}\int_0^{\frac{3}{4}} [C - 1.14\lambda - \lambda g_1 - \lambda g_2]\,dg_1\,dg_2 +$$

$$2\int_{\frac{1}{4}}^{1}\int_0^{1-g_1} [C - 1.14\lambda - \lambda g_1 - \lambda g_2]\,dg_1\,dg_2$$

$$+\int_0^{\frac{1}{4}}\int_{\frac{3}{4}}^{1} [C - 1.65\lambda - \lambda g_1 - \lambda(1 - g_2)]\,dg_2\,dg_1$$

APPENDIX C

Even when firms are 'local monopolists', price cutting incentives are lower with product compatibility.

Define $q(P_{ij})$, the demand for system X_{ij} when systems do not directly compete with each other. With consumers uniformly distributed on the square, $q'(P_{ij}) < 0$. With incompatibility, firm A's maximization problem is :

$$\underset{P_{1A}\ P_{2A}}{MAX} \quad [P_{1A} + P_{2A}]\ q(P_{AA})$$

After imposing $P_{1A} = P_{2A} = P_I^*$ in the first order conditions, they can be rewritten as :

$$q(2P_I^*) + 2P_I^*\ q'(2P_I^*) = 0 \qquad (1)$$

With compatibility, the first order conditions can be written as :

$$2q(2P_C^*) + 3P_C^*\ q'(2P_C^*) = 0 \qquad (2)$$

Comparing (1) and (2), it is clear that $P_C^* > P_I^*$. Intuitively, a switch from incompatibility to compatibility has two opposing effects on the firms' incentives to cut

prices. On the one hand, cutting prices increases demand by more with compatibility (at given prices, $3q' > 2q'$). On the other hand, it also implies a larger loss of revenue on "existing sales" (2q instead of q). The latter effect dominates.

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